Int. J. on Recent Trends in Engineering and Technology, Vol. 9, No. 1, July 2013

Study and Implementation of Advanced Control and Optimization for Ethylene Furnace using DeltaV System

Snehlata K.Sargar, Shilpa Y.Sondkar
Dept. of Instrumentation Engg. Vishwakarma Institute of Technology, Pune, India.
Email: snehalatasargar30@gmail.com
Dept. of Instrumentation Engg. Vishwakarma Institute of Technology, Pune, India.
Email: shilpa.sondkar@vit.edu

***Abstract*— This paper relates to study of advanced control and optimization of Ethylene furnace by using Model Predictive Control Professional (MPCPro) block of deltaV system and also some efforts are made for Implementation of severity control for part of Ethylene Furnace. Control and optimization of Ethylene Furnace is designed for MPCPro block, built in deltaV control studio. This software package consist of large number of control modules.**

Model of severity control for process zone-2 is developed for process with regulatory loops and this model is further used in MPCPro block of deltaV system. Control is generated using new control definition and then we verify the performance of process for PID control and for MPC at supervisory level with regulatory loops. The objective behind using MPC is there are 4 main challenges to restrict the process for maximum formation of ethylene are short residence time, controlled pressure, controlled temperature, steam to hydrocarbon ratio. The process is also get affected by the disturbances like Fuel BTU, Feed inlet temperature these issues are get registered while using MPC

Index Terms*— Control & Optimization, Ethylene Furnace, Model Predictive Control(MPC)

I. Introduction

The MPC is control strategy that minimizes, the predicted future error along the prediction horizon at each sampling rate considering the constraints on the limits of controlled variable and input moves. From the calculated control sequence only first move is implemented and whole procedure is repeated every time.[1] MPC is developed technology and used to implement in oil refineries which is having constrained, multivariable control. This control strategy explicitly use control model to predict future response of plant & take required action through Optimization [3]. MPC supervise the regulatory loops. The PID (Proportional, Integral and Derivative) takes set point from MPC through manipulated variables of MPC. In this case regulatory controller gives control in acceptable region. But in case of fluctuation in process due to disturbances or change in set point of manipulated variables, regulatory loops gives unsatisfactory performance. Hence to overcome these limitations MPC is placed at supervisory level. Ethylene is produced mainly by thermal cracking of hydrocarbons in the presence of steam from recovery of refinery cracked gas.

As Honggang Wang [2] discussed application of advanced severity control improved the operation of ethylene crackers in Sinopec's Nanjing 800000 tones/year ethylene plant. The estimated benefit is nearly $2.6 million /year with payback period less than 6 weeks. By considering these benefits, we tried to implement severity control of Process Zone-2 of Ethylene Furnace by using Predict Pro block deltaV system. By increasing the stability of severity, the consistency of process yield is improved which in turn enhance stability of downstream recovery section and reduce the operating cost.

II. Process Description-Ethylene Furnace

A. Chemical Properties

Ethylene is very reactive and it will undergo all typical reactions of short chain olefins. As ethylene is very reactive in nature it has gained importance as a chemical building block. During production of ethylene complex product mixtures are also get formed.

B. Production of Ethylene from Pyrolysis of Hydrocarbon

Major part of worldwide annual commercial production of ethylene is based on thermal cracking of hydrocarbons. The production of ethylene is carried by process called cracking in the presence of steam. A hydrocarbon stream mixed with steam is heated by heat exchanger against flue gas in the convection section to cracking tempt which is dependent upon feedstock .This is highly endothermic reaction. The product after reaction is at 800 to 850Úc and it is cooled at 550-650Úc within short period of time to prevent degradation of highly reactive product by secondary reaction.

C. Cracking Condition

To show the complexity of chemical reactions the cracking of ethane is ethylene is discussed here.
A simple reaction equation is

$$C2H6 \rightarrow C2H4 + H2 \qquad (1)$$

This reaction in Equation 1 is main reaction but this is not the only one reaction occurring in the process. At lower conversion ethylene, hydrogen, ethane, methane, acetylene, propene , propen, butane, benzene, tolune and heavier component also present. In the chain initiation step.

DOI: 01.IJRTET.9.1.43

Initiation

$$C2H6 \rightarrow CH3^* + CH3^* \quad (2)$$

Ethane is split into two methyl radicals in the chain initiation step as in Equation 2. The methyl radical reacts with an Ethane molecule to produce an Ethyl radical.

Propagation

Ethyl Radical decomposes to ethylene & hydrogen atom

$$CH3^* + C2H6 \rightarrow CH4 + C2H5^* \quad (3)$$

The hydrogen atom reacts with another ethane molecule to give a molecule of hydrogen & new ethyl radical.

Termination of chain

$$H^* + H^* \rightarrow H2 \quad (4)$$
$$CH3 + H^* \rightarrow CH4$$
$$H^* + C2H5^* \rightarrow C2H6$$
$$C2H5^* + CH3^* \rightarrow C3H8^*$$
$$C2H5^* + C2H5^* \rightarrow C4h10$$

To start new chain (equation 2-4) new methyl or ethyl radicals or new hydrogen atom must be generated on termination of chain propagation. Cracking of hydrogen in steam crackers is summarized as follows:

Primary Reactions Feedstock Steam → Ethylene propylene acetylene hydrogen methane etc. →Secondary reaction C4 products, C5 products, C6 products aromatics C7 products, heavier products.

III. Challenges During Furnace Control

A. *Residence Time*

Long residence time causes secondary reactions whereas short residence time increases the yield of primary products.

B. *Partial Pressure*

Molecules decreases, increasing pressure favour the secondary products. One function of steam present in the system is to reduce hydrocarbon partial pressure and thus favour the formation of primary products.

C. *Temperature*

The reaction involved in the formation of secondary products is favoured by lower temperature. Hence, special temperature profile is applied with cracking coil to avoid long residence time at lower temperature

D. *Steam to Hydrocarbon Ratio*

For maximed formation Ethylene steam to hydrocarbon ratio is maintained constant throughout the process.

IV. MPC Theory

MPC calculate the sequence of control moves so that predicted response moves to set point in optimal manner.

Figure.1shows the block diagram of MPC. Model predicts the current value of output variables. Model acts in parallel with process and residual i.e. difference between actual & predicted output serve as feedback signal. Targets are also called as set point for control calculation is determined

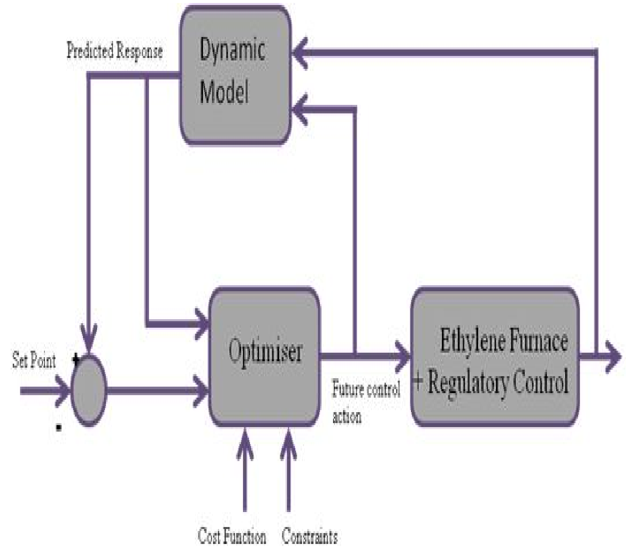


Figure 1. Block Diagram of Model Predictive Controller

by optimizer based on steady state model. Due to variation in process condition and economic data such as prices and cost, variation occur in constraints. Optimum value of set point will get changed frequently due to variation in process condition. In MPC set points are calculated at each control calculation.

V. Z2 Severity model development and controller generation

A. *Initial Controller Design*

As discussed in introduction we tried to implement severity control of Process Zone-2 of Ethylene Furnace by using Predict Pro block of deltaV system. By increasing the stability of severity, the consistency of process yield is improved which in turn enhance stability of downstream recovery section and reduce the operating cost.

The primary aim is how much ethylene is being produced during the cracking. The factors which majorly affect the production of ethylene are the amount of feed and energy given to furnace. In furnace feed is converted into gaseous mixture. The conversion means the number of moles of feed ethane which are cracked in furnace.

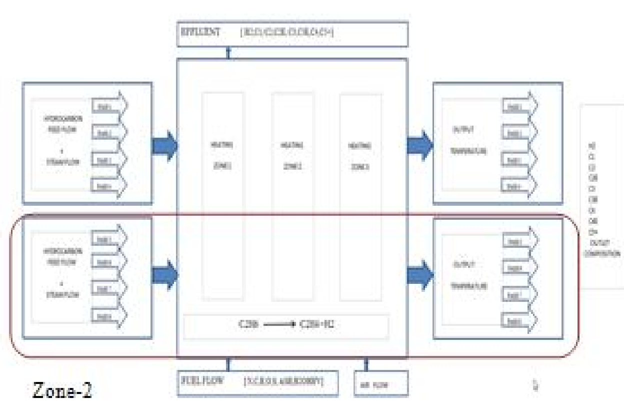


Figure 2. Highlights Process Zone-2

DOI: 01.IJRTET.9.1.43

Severity= (Methane/ Ethylene)

Severity is ratio of two constituents in the product stream flowing through cracking furnace. Selectivity is used as an indication of Severity. Process severity is maintained by maximizing the production of ethylene in the ethylene cracking furnace. Fig.2 content diagram which highlights process zone-2 whose model is being developed.

To control severity, a control strategy is derived in which manipulate heat supplied to the cracking furnace. This strategy forces the heat supplied to a level which will give maximum ethylene production rate. To maintain proper heat during the process, can manipulate feed flows of the process. Hence, Basic principle behind maintaining severity is manipulation of heat input to the cracking furnace by utilizing feed flow to the furnace as showed in Figure 3.

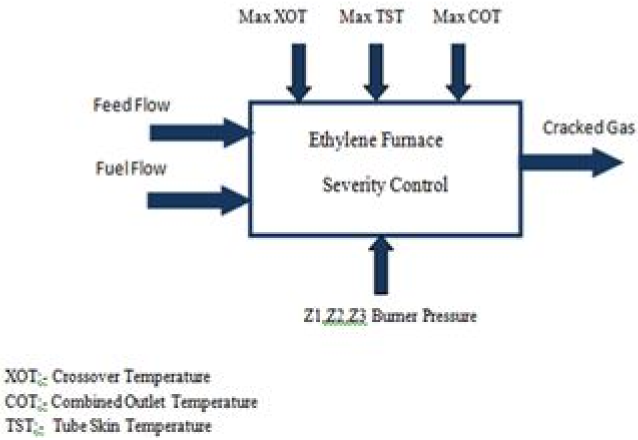


Figure 3. Block Diagram representing Severity control principle

Manipulated Variables	Controlled Variables	Constraints	Disturbances Variables
1]Pass 5 Flow	1] Z2 Severity.	1] Z2 Max Crossover Temp	1] Fuel BTU
2]Pass 6Flow	2] Z2 Feed.	2] Stack O2	2] Z2 Feed Inlet Temp
3]Pass 7Flow	3] T Offset_6	3] Z2 Max TST	
4]Pass 8Flow	4] T Offset_7	4] Z2 COT	
5]Z1 Fuel Flow.	5] T Offset_8	5] Z1 Burner Pressure	
6]Z2 Fuel Flow.		6] Z2 Burner Pressure	
7]Z3 Fuel Flow		7] Z3 Burner Pressure	

To maintain severity heat supplied to the process is manipulated. This case considers one process zone i.e. Process Zone-2. Hence to maintain the rate of production of ethylene of that zone, can manipulate the fuel flow of particular zone and amount of feed entering in that zone through each pass. Process Zone-2 achieves heat level from 3 firing zones (Z1, Z2, Z3) hence, Z1 Fuel Flow, Z2 Fuel Flow, Z3 Fuel Flow are manipulated. Passes which gives feed to the process zone-2 i.e. Pass 5 flow, Pass 6 flow, Pass 7 flow, Pass 8 flow are also manipulated.

In the figure 4 T offset_6, T offset_7, T offset_8 are the temperature difference of each pass with respect to temperature of pass 5. If the difference of temperature between one reference pass and another pass goes up then pass with low temperature cause under cracking and pass with high temperature cause over cracking which hampers the severity of furnace. Hence controlling offset temperature works to maintain throughput by manipulating feed flow of 4 passes and fuel flow of each firing zone.

B. Test Setup

Model Identification is major part of MPC system

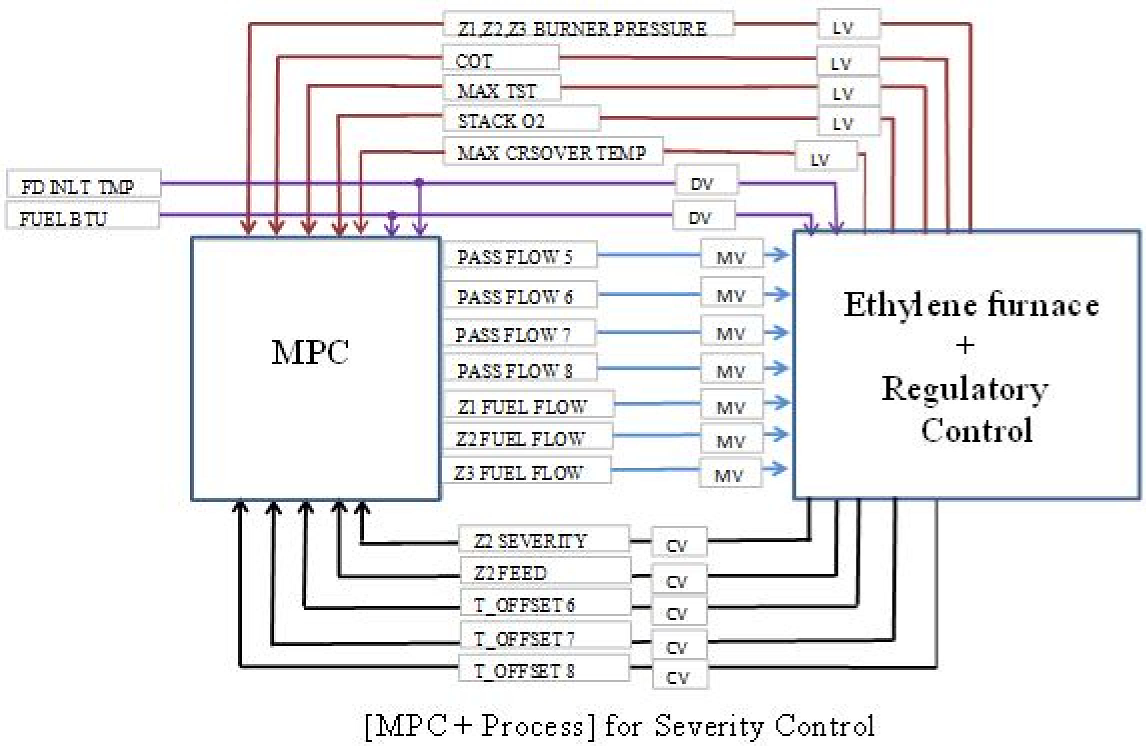


Figure 4. Block Diagram of MPC with Process for Severity control

DOI: 01.IJRTET.9.1.43

Int. J. on Recent Trends in Engineering and Technology, Vol. 9, No. 1, July 2013

implementation. Process model is identified from process input, output data. . To identify model accurately, the exciting signals given for testing , that given signal must excite both low frequency (steady state) & medium to high frequency (dynamic) dynamics of process.If any of the parameter i.e.Manipulated Variable(MV),Controlled Variable(CV),Limit Variable(LV) i.e Constraints),disturbances variable (DV) get limited during test then test will get aborted. Considering all these parameters, we give 5% of process value change in manipulated variable as a testing signal in the form of pseudo random binary sequence (PRBS). Time required for steady state is calculated time in second to respond the process for input changes .The length of test depends upon tome required for process to reach the steady state. Typical steady state estimation is dead time multiplied by 4. As Ethylene furnace is having slow dynamics, 240 seconds of time is given as a steady state time for testing. In this closed loop testing the actual mode of MPC block changes to LO. [4]

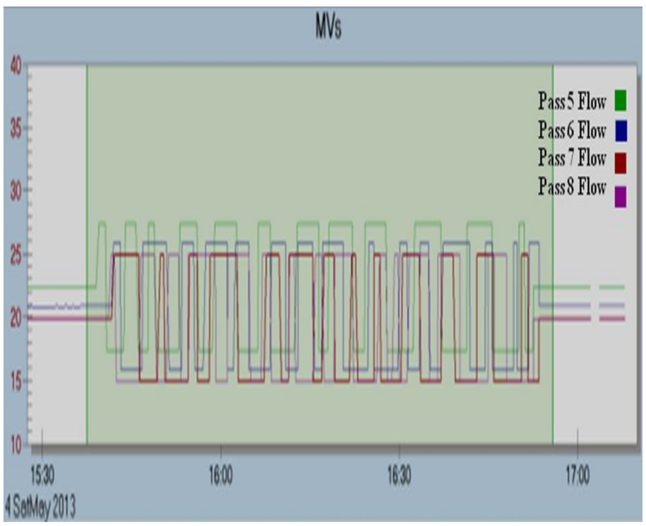


Figure 5. PRBS given to Manipulated input Pass 5, Pass 6,Pass.7,Pass 8

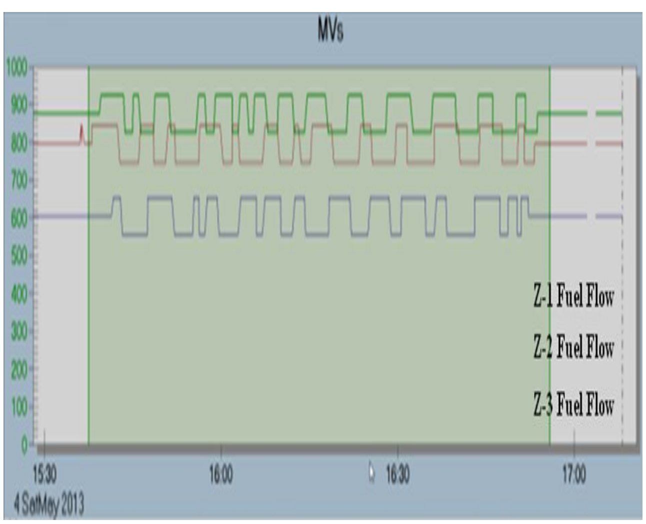


Figure 6. PRBS given to Manipulated input Z1 Fuel Flow, Z2 Fuel Flow, Z3 Fuel flow

Figure 5 shows pseudo random binary sequence given to pass 5, pass 6, pass 7, pass 8 flow. Figure 6 shows pseudo

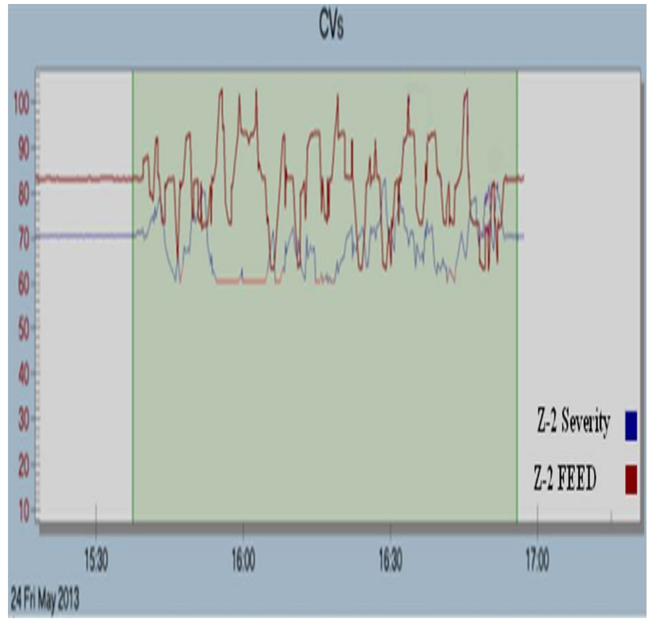


Figure 7 .Response of Controlled Variables Z-2 Severity and Z-2 FEED due to PRBS in Manipulated Variables

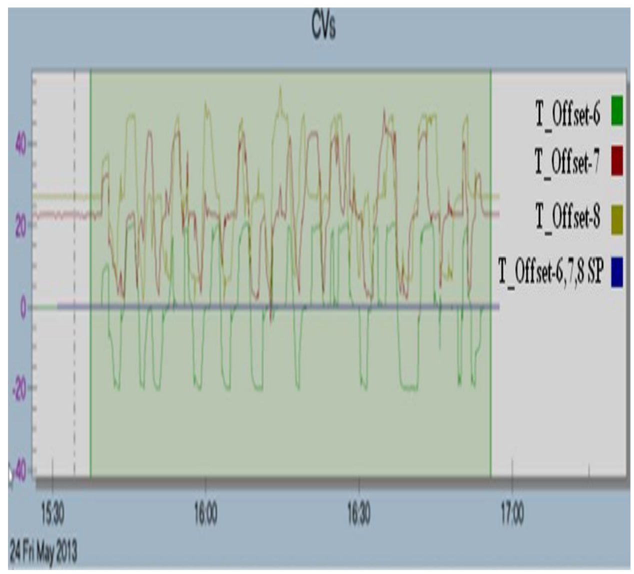


Figure 8.. Response of Controlled Variables T Offset_6, T Offset_7, T Offset_8 due to PRBS in Manipulated Variable

random binary sequence given to Z1 Fuel Flow, Z2 Fuel Flow, Z3 Fuel flow. Figure 7 shows Response of Controlled Variables Z-2 Severity and Z-2 FEED due to PRBS in Manipulated Variables. Figure 8 shows Response of Controlled Variables Z-2 Severity and Z-2 FEED due to PRBS in Manipulated Variables.

Two techniques are used in model identification by deltaV i.e. FIR technique and ARX technique. To describe the dynamics of simple first order plus dead time system generally 30 to 120 coefficients are required for impulse response. 120 or more coefficients are required for an impulse response to completely describe the model. The main disadvantages of FIR identifiers is that, Using approximately 120 coefficients per input-output pair for identifying the step response with full prediction horizon causes over fitting & significant

DOI: 01.IJRTET.9.1.43

parameter uncertainty.

1) *FIR Model.*

To avoid over fitting, can use short horizon of 40 to 60 points . By using short horizon approach model can provide initial part of step response & causes difficulty for slow dynamics processes also difficult to define dead time.

$$\Delta Yk= \sum_{i=1}^{P} hi\ \Delta Uk \tag{5}$$

P:-Prediction horizon.

Equation 5 shows formula used for calculation of FIR model response. To overcome the this difficulty ARX model approach is used.

2) ARX Model.

One of the advantages of ARX model over FIR model is that it has less number of coefficient than that of FIR model. For MIMO process in both ARX & FIR Model super position is applied on both inputs & outputs. A step is applied on one of the input of MIMO system & ARX model is developed . Practically order of 4 is used.

$$Yk= \sum_{i=1}^{V} aiy(k-i) + \sum_{i=1}^{A} bi\,u(k-d-i) \tag{6}$$

A:-Autoregressive order.

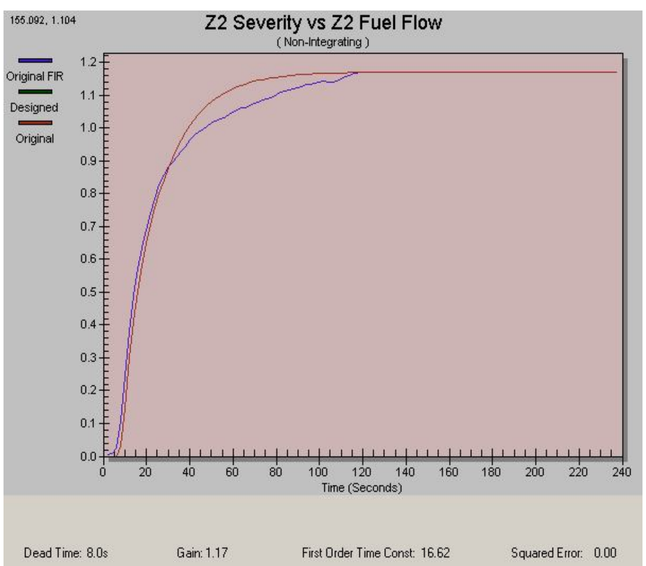
V:-Moving Order.

D:-Dead time.

In this way,by using Equation 6 part of ARX model can be obtained for that particular input only.[5] To obtain complete model, in similar fashion, step input can be applied for remaining part of the process. Figure.9. shows graphs obtained for ARX & FIR response for one pair of controlled and manipulated variable.

Following Table.1 shows relation of each controlled variable with manipulated variable in newly developed model in terms of transfer function as in equation 7.

$$Y(S)/U(S)=[(Ke^{\wedge}s)/(Ts+1)] \tag{7}$$



FIR Response

ARX Response

Figure 9. . ARX and FIR Response

TABLE 1. REPRESENTING THE VALUES OF K, T, S

MV / CV		*Pass5 Flow*	*Pass 6 Flow*	*Pass 7 Flow*	*Pass 8 Flow*	*Z-1 Fuel Flow*	*Z-2 Fuel Flow*	*Z-3 Fuel Flow*
Z-2 Severity	K= T= ?=	-0.4 11.08 6	-0.4 11.08 6	-0.45 6 15.23	- 0.41 18 2	0 0 0	1.17 16.62 8	0.22 15.23 10
Z-2 Feed	K= T= ?=	0.97 4.15 6	0.99 4.62 2	0.94 4.62 2	0.96 4.62 2	0 0 0	0 0 0	0 0 0
T_Offset_6	K= T= ?=	1.95 3.69 8	-1.95 5.84 8	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0
T_Offset_7	K= T= ?=	1.98 4.62 8	0 0 0	-1.93 7.58 10	0 0 0	0 0 0	0 0 0	0 0 0
T_Offset_8	K= T= ?=	1.99 5.54 10	0 0 0	0 0 0	- 1.94 7.88 10	0 0 0	0 0 0	0 0 0
Z-2 Max XOT	K= T= ?=	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.24 16.02 6	0 0 0
Stack O_2	K= T= ?=	0 0 0	0 0 0	0 0 0	0 0 0	-0.55 13.51 10	-0.62 12.46 10	0 0 0
Z-2 MAX TST	K= T= ?=	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.19 11.08 8	0 0 0
Z2 COT	K= T= ?=	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.23 12.46 8	0 0 0
Z-1 Burner Pressure	K= T= ?=	0 0 0	0 0 0	0 0 0	0 0 0	0.92 14.27 8	0 0 0	0 0 0
Z-2 Burner Pressure	K= T= ?=	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.91 9.07 6	0 0 0
Z-3 Burner Pressure	K= T= ?=	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.47 20.77 2

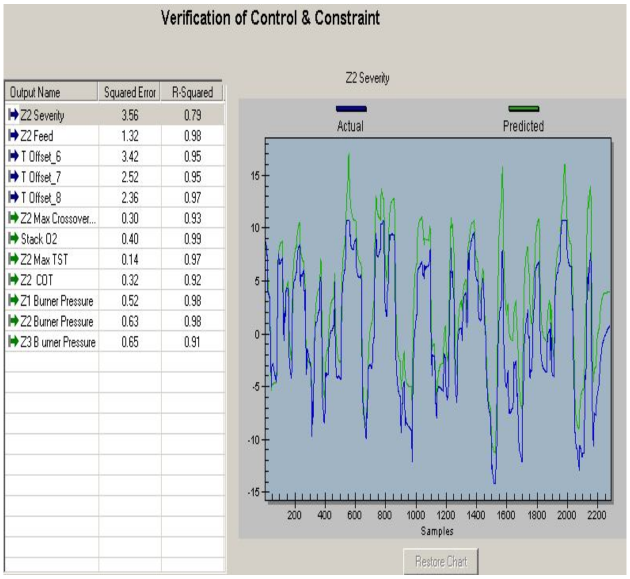
C. Model Development and Verification.

By observing the performance of controlled variables while testing undesired data can be excluded during development of model. By choosing Auto generate key on the display model is generated for selected data. In Figure.10. blue colour shows actual value and green colour shows predicted value. By observing the difference between two graphs the model is verified. As there is no much difference in graphs model is accurate enough. At slopes actual and predicted values match exactly with each other hence for changing values of variable model give correct response. At peaks it does not have exact match with each other hence at limiting sides control is not that much tighter.[4] When model makes perfect prediction at that time value of R- squared is 1. But practically R-squared never be 1, it is generally more than 0.5. In the developed model of Z-2 Severity R-squared value is greater than 0.8 hence, model is accurate.[6].

D. Control System Design.

When model correctly reflects process dynamics and

DOI: 01.IJRTET.9.1.43

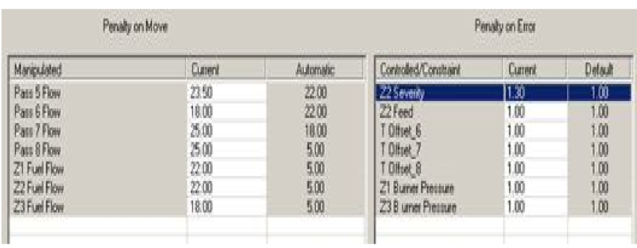


Verification of Control & Constraint

Output Name	Squared Error	R-Squared
Z2 Severity	3.56	0.79
Z2 Feed	1.32	0.98
T Offset_6	3.42	0.95
T Offset_7	2.52	0.95
T Offset_8	2.36	0.97
Z2 Max Crossover...	0.30	0.93
Stack O2	0.40	0.99
Z2 Max TST	0.14	0.97
Z2 COT	0.32	0.92
Z1 Burner Pressure	0.52	0.98
Z2 Burner Pressure	0.63	0.98
Z3 B urner Pressure	0.65	0.91

Figure 10 Verification Of Model

accuracy of model is confirmed then generation of controller is the next step. By using the key auto generate controller is generated automatically. It is recommended to generate the controller at default values, but to obtain enhanced performance some modifications are made in penalty on move & penalty on error factors as shown in Figure 11. In this Z2-severity model some modifications are made in POE (Penalty on Error) and POM (Penalty on Move) to address some special requirements.



Penalty on Move

Manipulated	Current	Automatic
Pass 5 Flow	23.50	22.00
Pass 6 Flow	18.00	22.00
Pass 7 Flow	25.00	18.00
Pass 8 Flow	25.00	5.00
Z1 Fuel Flow	22.00	5.00
Z2 Fuel Flow	22.00	5.00
Z3 Fuel Flow	18.00	5.00

Penalty on Error

Controlled/Constraint	Current	Default
Z2 Severity	1.30	1.00
Z2 Feed	1.00	1.00
T Offset_6	1.00	1.00
T Offset_7	1.00	1.00
T Offset_8	1.00	1.00
Z1 Burner Pressure	1.00	1.00
Z3 B urner Pressure	1.00	1.00

Figure 11. POM and POE values for newly generated Controller

E. Performance Monitoring.

1) CV Variability and MV Utilization.

Achievable performance PID is limited is due to interaction, which is feature of multivariable process. In same case MPC can improve performance & reduce variable variations. PID control becomes insufficient to achieve the desired value of Z-2 Severity (CV), when Feed flow value get fluctuated from respective value for that particular value of Z-2 Severity. But in case of MPC when value of Z2 Feed will get changed, controlled variable Z2 severity track the set point by manipulating the variables Z2 Fuel Flow and Z3 fuel flow and also by doing the variation in limit variables within constrained range as shown in Figure 12. At the same time other controlled variables have tighter control, hence CV Variability by MV utilization can be achieved.

2) Effect of Disturbances.

At the time of identification of model MPC considers some disturbance variables. The effect of these measured

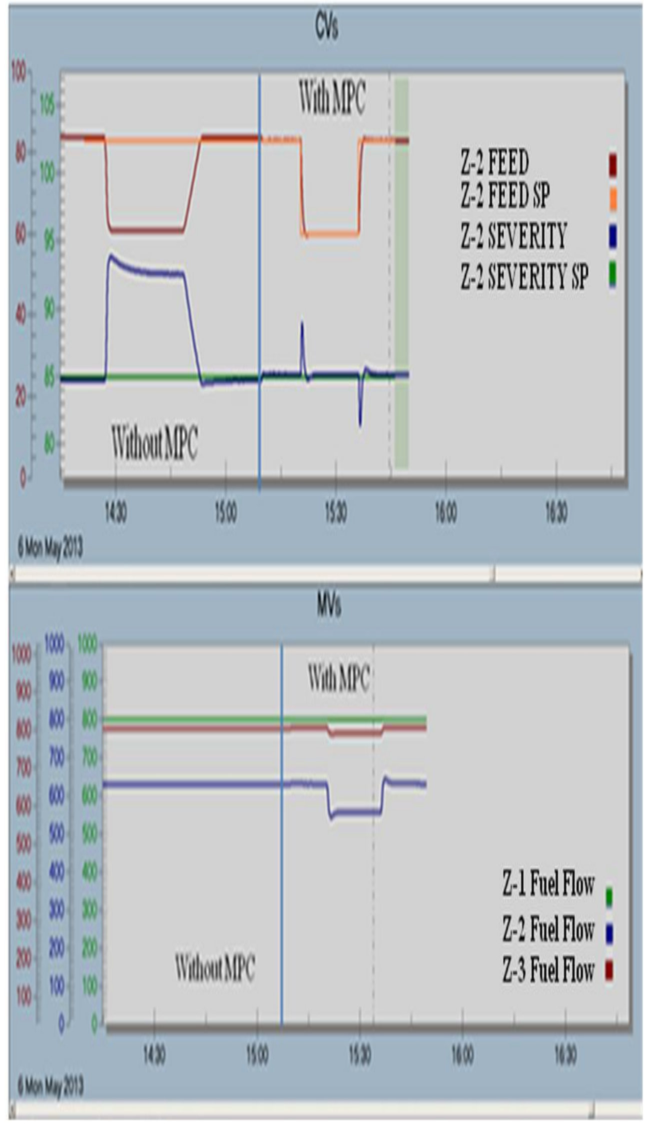


Figure 12 Effect of Feed value upon the Z-2 Severity (CV) with MPC and without MPC

disturbance variables is nullified in MPC control. When there are disturbances get introduced in the process as shown in Figure 13, controlled variable get deviated from particular set point.

Here Feed Inlet temperature is disturbance variable. Effect of this DV will get observed by introducing step change in it. In PID control when feed inlet temperature changes, Z-2 Severity of furnace will get deviated from desired value and it does not track desired value unless disturbances will get eliminated from the process. The

reason behind this is that PID will control only single variable for control. But in case of implementation of MPC when change in Feed inlet temperature is introduced in process at that instant However in PID control effect of disturbance is not addressed at all.

Conclusions

The implementation of control and optimization of Ethylene Furnace of Process Zone-2 is done by using MPCPro

DOI: 01.IJRTET.9.1.43

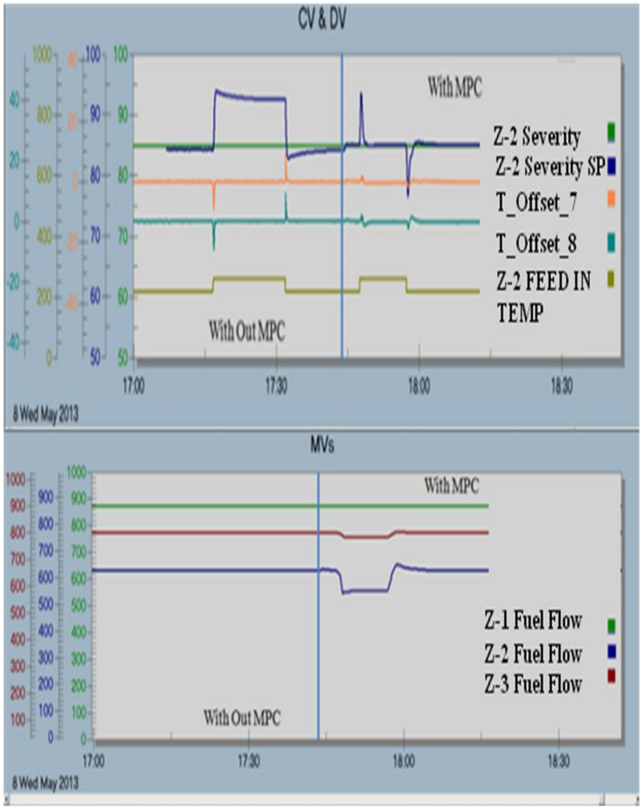


Figure 13 Effect of disturbances on variables with MPC and without MPC

built in deltaV system. MPCPro block built in deltaV system gives easiest way of MPC implementation. By using MPC block CV variabllity with MV utilization is achieved. This can be observed in MPCOperate Pro by considering controlled variable, Z-2 Severity as major controlled variable with utilization of other variables. Effect of measured disturbances is also nullified.

Acknowledgment

The authors are thankful to Emerson Export Engineering Centre, Pune for giving the opportunity to work on this project. The authors also thank Koustubh Palnitkar, Archis Labhe and Sachin Soman for their technical support. The authors also acknowledge Prof. (Dr.) J. V. Kulkarni for his extending support for this project. Moral support from Kakasaheb Sargar is also appreciated.

References

[1] Dale E. Seborg, Thomas F.Edgar,Duncan A. Mellichamp, "Process Dynamics and Control," 2 nd ed., John Willey & Sons, Inc, 2004

[2] Honggang Wang, Zhenlei Wang, Hua Mei, Feng Quian, Zhiwu Tang; Sinopec Yangzi Petrochemical Co.Ltd Nanjing, China; "Intelligent Severity control stabilizes ethylene crackers"; Oil & Gas Journal| Feb 7,2011

[3] Mark L.Darby, Michael Nikolaou, "MPC Current practice and challenges", Control Engineering Practice 20(2012) 328-342

[4] Books on-line, deltaV DCS Documentation,Emerson Process Management, USA,2012 (deltaV 9.3)

[5] Willy Wojsznis, John Gudaz,Terry Blevins, Ashish Mehta, "Practical approach to tunning MPC," ISA Transactions 42 (2003) 149-162.

[6] Scott Fortmann Roe, " Accurately Measuring Model Prediction Error." Essay of Scott Fortmann Roe, May 2012.

DOI: 01.IJRTET.9.1.43